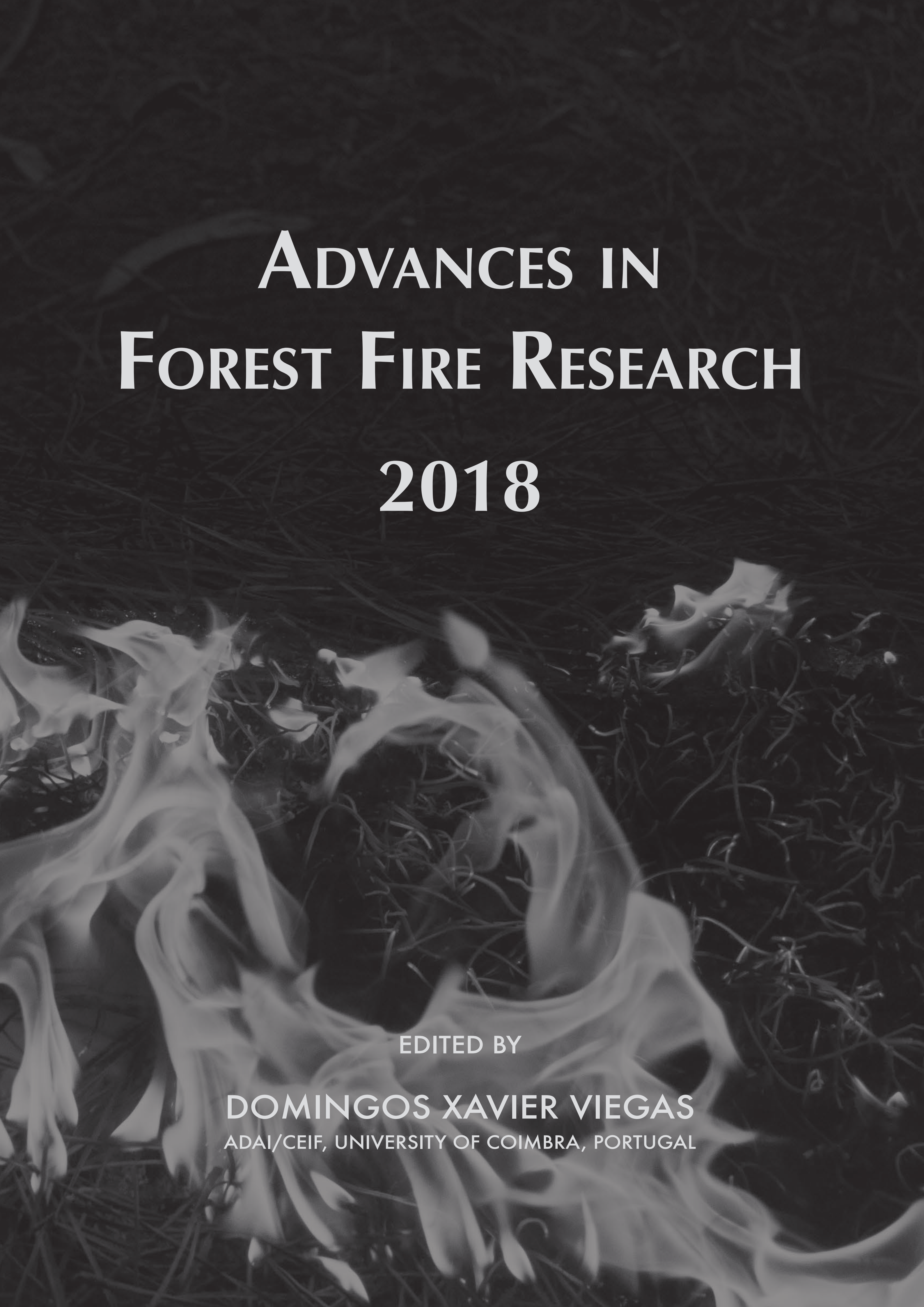

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Flammability and combustibility of potential species for use as fuel breaks

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Abstract

In order to minimize the incidence and magnitude of fires, preventive silviculture proposes the establishment of fuel breaks, which is strips of vegetation with species of lower flammability than those of the main cultivation, with the aim of reducing or avoiding fire spread. The objective of the study was to evaluate the flammability and combustibility of eight ornamental species by means of cluster analysis, and indicate their potential for use as fuel breaks. Flammability was determined according to the methodology recommended by Valette (1990) and Petriccione (2006). For each evaluated species, 50 firing repetitions were performed in the epirradiator, each one consisting of 1 ± 0.1 g of fine green combustible material (Ø < 0.7 cm). In the tests the following combustion characteristics were analyzed: Ignition Time (IT), Ignition Frequency (IF), Duration of Combustion (DC) and Flame Height (FH). The fire behavior components were measured according to the methodology presented by Batista and Biondi (2009). The experimental burns were carried out in 1 m² (1 m x 1 m) plots, with a load of 1 kg.m² for all treatments. The following parameters were analyzed: Flame Height (FHh), Speed of Propagation (SP) and Residual Material (RM). The Lower Calorific Value (LCV) was determined with an isoperibol calorimeter, following the standard of ABNT NBR 8633/1984 and was expressed by calories per gram (kcal.kg-1). The Flammability Value (FV) was obtained according to the methodology applied by Vallete (1990) and the fire intensity was estimated using the Byram equation (1959). The parameters IF, IT, DC and FH of flammability and FHh, SP, RM and LCV of combustibility were submitted to cluster analysis. *Schinus terebinthifolius* and *Bougainvillea glabra* were the species that presented the lowest values of flammability and combustibility being classified in the null class, as well as *Rhododendron simsii* in the low classification class. *Jasminum mesnyi* has low combustibility, but high flammability, not being indicated for composing a fuel break. *Viburnum odoratissimum* showed low ignition capacity, but its combustibility presented superior parameters when compared to *Pinus taeda*. *Magnolia grandiflora*, even with some inferior parameters than those of *P. taeda*, has the lowest IT, being highly flammable and not recommended for use in fuel breaks. *S. terebinthfolius*, *B. glabra* and *R. simsii* are the species indicated for use as fuel breaks.

Keywords: forest fires, preventive silviculture, calorimetry, combustible material.

1. Introduction

Natural disturbances are important for ecosystems functioning and, under normal conditions in healthy ecosystems, are an intrinsic part of nature. However, catastrophic events can seriously affect environmental functions and human activities (Montagné-Huck and Brunette 2018).

Forest fires at the Wildland-Urban Interface (WUI) are a threat to communities in many countries (Mell *et al*. 2010) and a growing problem with social and economic impacts (Molina *et al*. 2017).

The main cause of forest fires at WUI is anthropogenic (Long-Fournel *et al.* 2013). A lack of awareness of the risk of forest fires is observed, since residents generally tend to underestimate it (Meldrum *et al.* 2015). The high population density and the negligent attitude of people who inhabit or transit these regions (Castillo *et al.* 2011), combined with long periods of drought and accumulation of combustible material (Mell *et al.*, 2010), increase the risk of ignition. In this context, it is possible to mention the recent events in Pedrógão Grande/Portugal (2017), Tathra/Australia (2018), New Mexico and Colorado/United States (2018).

Thus, land use planning should be considered as an important component of fire risk management (Syphard *et al.* 2013). In view of the vulnerability of WUI to forest fires, due to the risk to human life and damage to residences (Long-Fournel *et al*. 2013), vegetation around homes becomes a major concern as it can facilitate the reach of fire in these structures (Castillo and Correa 2012; Ganteaume *et al.* 2013).

One method to mitigate the probability of homes being damaged by fire is to reduce the flammability of surrounding areas (Molina *et al.* 2017). In this context, preventive silviculture proposes the establishment of fuel breaks, which is strips of vegetation with species of lower flammability and combustibility than those of the main cultivation, in order to reduce or prevent the fire spread (Haltenhoff 2006).

To determinate the species to compose fuel breaks, it is evaluated: i) flammability, which is the capacity of the vegetation to burn; and ii) combustibility, which characterizes the ability of the combustible material to maintain the combustion process and to propagate the fire (Soares *et al.* 2017). Thus, the objective of the study was to evaluate the flammability and combustibility of eight ornamental species, by means of cluster analysis, and indicate their potential for use as fuel breaks.

2. Material and methods

The flammability and combustibility tests were carried out in the Forest Fire Laboratory of the Federal University of Paraná, Brazil.

Nine potential species were selected for use as fuel breaks: *Bougainvillea glabra* Choisy., *Casearia sylvestris* Sw., *Jasminum mesnyi* Hance., *Magnolia grandiflora* L., *Michelia champaca* L., *Rhododendron simsii* Planch., *Schinus terebinthifolius* Raddi and *Viburnum odoratissimum* Ker Gral. *Pinus taeda* L. was used as control of the experiment because it is a species of high economic interest.

2.1. Flammability test

Flammability was determined according to the methodology recommended by Valette (1990) and Petriccione (2006). For each evaluated species, 50 firing repetitions were performed in the epirradiator, each one consisting of 1 ± 0.1 g of fine green combustible material (< 0.7 cm in diameter) (Figure 1).

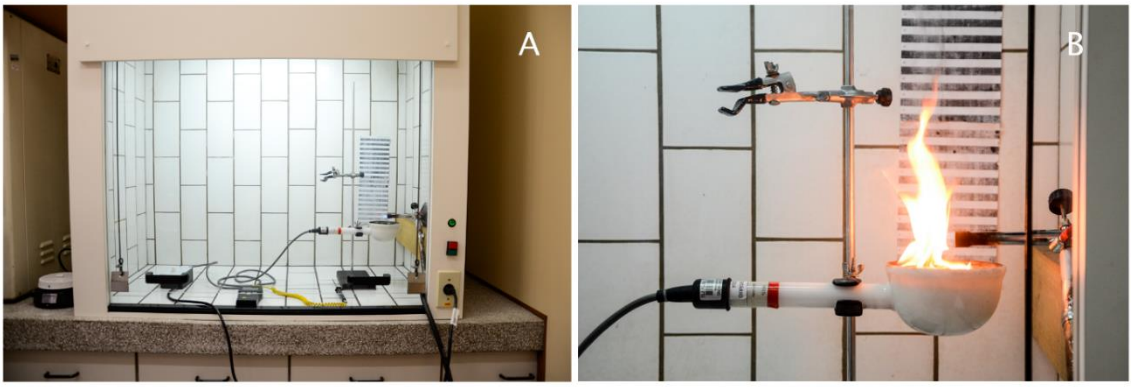

Figure 1 - Epirradiator in the fume hood (A) and epirradiador test (B)

In the tests, the following combustion characteristics were analyzed: ignition time (IT), in seconds, time of complete combustion (TC), in seconds, maximum flame height (FH), in centimeters and ignition frequency (IF), in percentage. IF is the percentage of repetitions in which ignition occurred, considering a maximum IT of 60 seconds. The burnings that exceeded this time were classified as "negative burning" and received standardized values: IT equal to 61 seconds; TC equal zero seconds and FH equal zero centimeters.

The flammability index (FI) of the selected species was obtained according to the IF and IT, varying as follow: 0 = very low flammable; 1 = low flammable; 2 = moderately flammable; 3 = flammable; 4 = very flammable; and 5 = extremely flammable (Table 1).

Table 1 - Classification of flammability according to the ignition time (IT), in seconds, and ignition frequency (IF), in percentage

IT (s)	IF (%)					
	≤ 50	50 - 79	80 - 84	85 - 89	90 - 94	> 94
> 32.5	0	0	0	1	1	2
27.6 – 32.5	0	0	1	1	2	2
22.6 – 27.5	0	0	1	2	2	2
17.6 – 22.5	1	1	2	2	3	3
12.6 – 17.5	1	1	2	3	3	4
< 12.6	1	2	3	3	4	5

2.2. Combustibility test

The fire behavior was measured according to the methodology presented by Batista and Biondi (2009). For each evaluated species, 10 repetitions of experimental burnings were carried out in 1 m² plots with a load of 1 kg of fine dry fuel material (< 0.7 cm in diameter), as presented in Figure 2. The experimental burnings were filmed for later data collection.

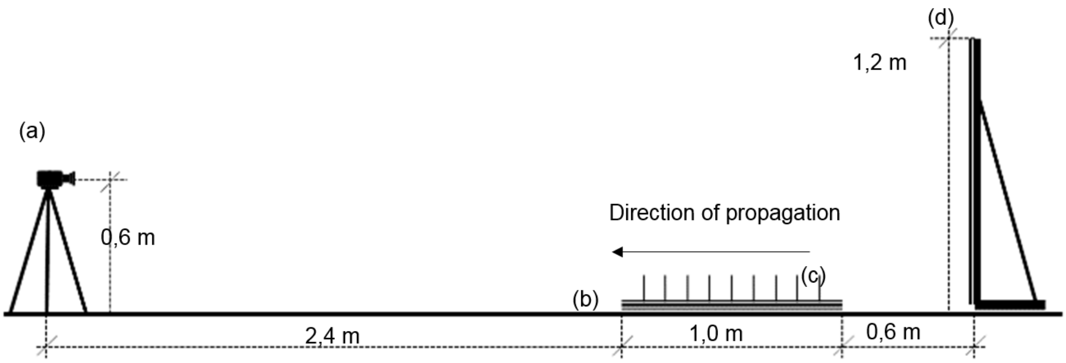

Figure 2 - Schematic illustration of components.

Note: (a) camera; (b) plot with fuel material; (c) ruler for speed of fire propagation determination; (d) panel for reading the flame height.

The following fire behavior parameters were analyzed: flame height, speed of propagation, residual material, fire intensity and lower calorific value, described below:

i. Flame length (FL), in centimeters: is obtained every 10 cm of fire propagation, having as reference a graduated rule. Eight observations are made per experimental burning. Subsequently, this variable was corrected as a function of the fire position in the plot and the flame height. For this, the following correction formulas were used:

For flame length greater than 60 cm (Equation 1):

$$\mathrm{Cf} = -(\mathrm{D} + 60) * \left[\frac{(\mathrm{FLv} - 60)}{400}\right] \quad (1)$$

For flame length less than 60 cm (Equation 2):

$$\mathrm{Cf} = +(\mathrm{D} + 60) * \left[\frac{(60 - \mathrm{FLv})}{400}\right] \qquad (2)$$

where: Cf = correction factor, in cm; D = distance of the flame in relation to the beginning of the burn, in cm; FLv = flame length shown in the video, in cm.

ii. Speed of propagation (Sp), in cm.s^{-1}: determined by the relation between pre-established distances and the time spent by the fire front line to travel through them. For each experimental burning, eight observations were obtained.

iii. Residual material (Rm), in g.m^{-2}: collected in the central area of the burning plot, using a template of 400 cm^2 (20 x 20 cm).

iv. Fire intensity (I), in kcal.m^{-1}.s^{-1}: obtained by the formula of Byram (1959) (Equation 3).

$$I = H.w.r \qquad (3)$$

where: I = fire intensity, in kcal.m^{-1}.s^{-1}; H = calorific value, in kcal.kg^{-1}; w = mass of available fuel material per area, in kg.m^{-2}; r = speed of fire propagation, in m.s^{-1}.

v. Lower calorific value (LCV), in kcal.kg^{-1}: determined with an isoperibol calorimeter, following the standard of ABNT (1984) NBR 8633.

2.3. Data analysis

The parameters of flammability: ignition frequency (IF), ignition time (IT), time of complete combustion (TC) and flame height (FH); and combustibility: flame length (FL), speed of propagation (Sp), residual material (Rm) and lower calorific value (LCV), were submitted to cluster analysis.

3. Results

In Table 2 are presented the parameters of flammability and combustibility and Figure 3 shows the cluster analysis of the studied species.

Table 2 - Values of flammability and combustibility parameters of the tested species

Species	Flammability				FI	Combustibility				Intensity
	IF	**IT**	**TC**	**FH**		**FL**	**Sp**	**Rm**	**LCV**	
Schinus terebinthifolius	14	58.4	9.6	11.9	**0**	1.7	1.6	1445.9	4037.3	**1.1**
Bougainvillea glabra	10	59.7	7.0	16.8	**0**	11.0	10.7	1643.8	3489.9	**6.2**
Michelia champaca	86	19.8	4.5	9.2	**1**	32.6	70.0	219.0	3707.8	**43.3**
Viburnum odoratissimum	88	23.3	5.4	11.9	**1**	32.1	48.8	200.9	3877.9	**31.5**
Rhododendron simsii	98	18.8	26.9	8.6	**2**	24.4	15.6	290.0	4454.5	**11.6**
Casearia sylvestris	96	17.5	5.5	13.7	**3**	23.3	32.4	395.7	4449.4	**24.0**
Pinus taeda	100	16.3	12.5	12.1	**3**	36.6	55.8	176.6	4701.0	**43.8**
Magnolia grandifolia	100	12.5	7.4	25.2	**4**	40.0	44.5	138.0	4259.3	**31.6**
Jasminym mesnyi	100	10.9	18.5	13.9	**4**	14.3	27.1	440.1	4438.3	**20.0**

Note: FI = Flammability index; 0 = very low flammable; 1 = low flammable; 2 = moderately flammable; 3 = flammable; 4 = very flammable; and 5 = extremely flammable.

S. terebinthifolius and *B. glabra* were classified as very low flammable (FI = 0), with an IT superior to that found by Molina *et al*. (2017) for species with low flammability in Spain. Kovalsyki *et al*. (2016), while studying the flammability of the same species, stated that both have shorter TC and FH, 1.3 s and 1.7 cm for *S. terebinthifolius* and 0.7 s and 1.2 cm for *B. glabra*, than what was found in the present study.

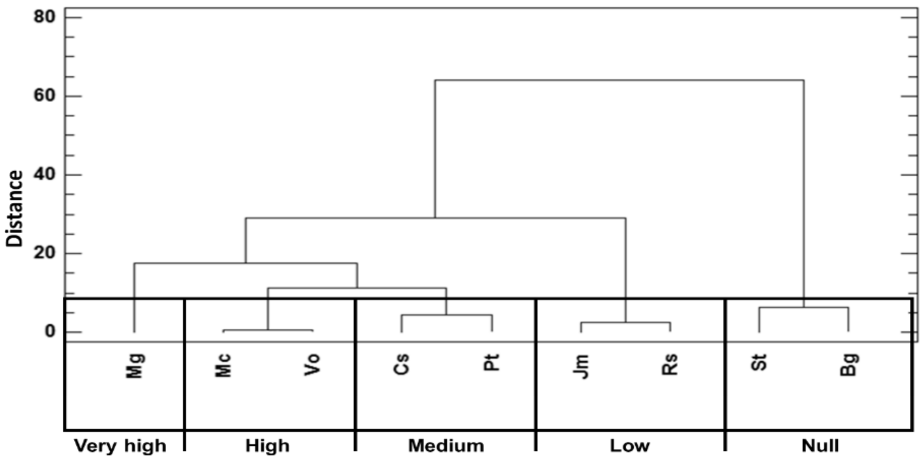

Figure 3 - Dendrogram according to the species flammability and combustibility

Another factor that favored the classification of *B. glabra* in class zero was a moisture content of 210.6% for this specie. The greater the moisture content, the greater the difficulty of material to ignite, where a high energy expenditure will be required to start the combustion process (White 2018).

Although *S. terebinthfolius* had a lower moisture content (142.4%) and higher flammability compared to other species tested in this study, such as *V. odoratissimum* (163.1%) and *M. champaca* (147.6%), this species can be used as fuel breaks. Due to its low combustibility, *S. terebinthfolius* represents a small chance of the fire to escape control, allowing the combat in safety (Soares *et al*. 2017).

J. mesnyi has low combustibility, however is very flammable, not being indicated to act as fuel break. Even being classified as moderately flammable, *R. simsii* ignition frequency and time of complete combustion show a greater capacity to ignite and keep the flames than those species with low flammability and combustibility. Even though the heat fluxes measured during forest fires have a magnitude greater than the heat sources used in laboratory studies, it is known that ignition sources (cigarettes, bonfires, sparks, etc.) do not need to have large heat fluxes (Fernandes and Cruz. 2012).

M. gradiflora, even with some parameters lower than those found for *P. taeda*, has the lowest IT and combustibility, but was characterized as very flammable, not being recommended for use as fuel breaks. Results found by Mola *et al*. (2014) indicated that the susceptibility and severity of fires in the Apalachicola Ravines, Florida - USA were higher after the increase in the number of individuals of *M. grandiflora*.

4. Conclusion

The cluster analysis showed to be effective in the classification of species according to their flammability and combustibility. *S. terebinthfolius*, *B. glabra* and *R. simsii* are the species indicated for use as fuel breaks.

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